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(56) Documents Cited
GB 2338107 A GB 2317053 A US 5798537 A

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(54) Abstract Title
Semiconductor light emitting devices

(57) The device comprises a sapphire substrate 1 having a porous surface layer or porous structure, an InAlGaN buffer layer 2, an n-type GaN layer 3, a Group III-V active layer 4, a p-type AlGaN hole emitting layer 10, a p-type InGaN contact layer 11 and a metallic ohmic contact. The device may be a laser or light emitting diode.

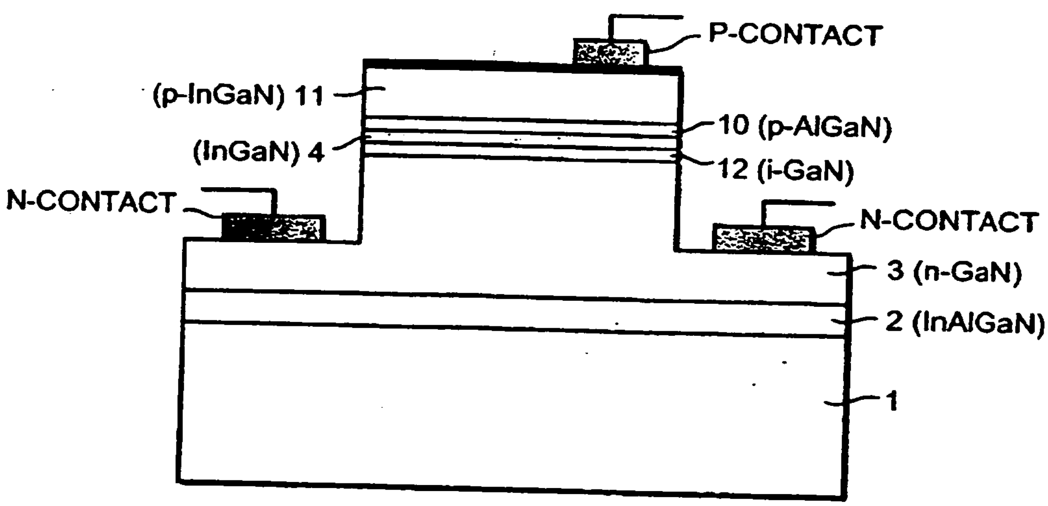

FIG. 3

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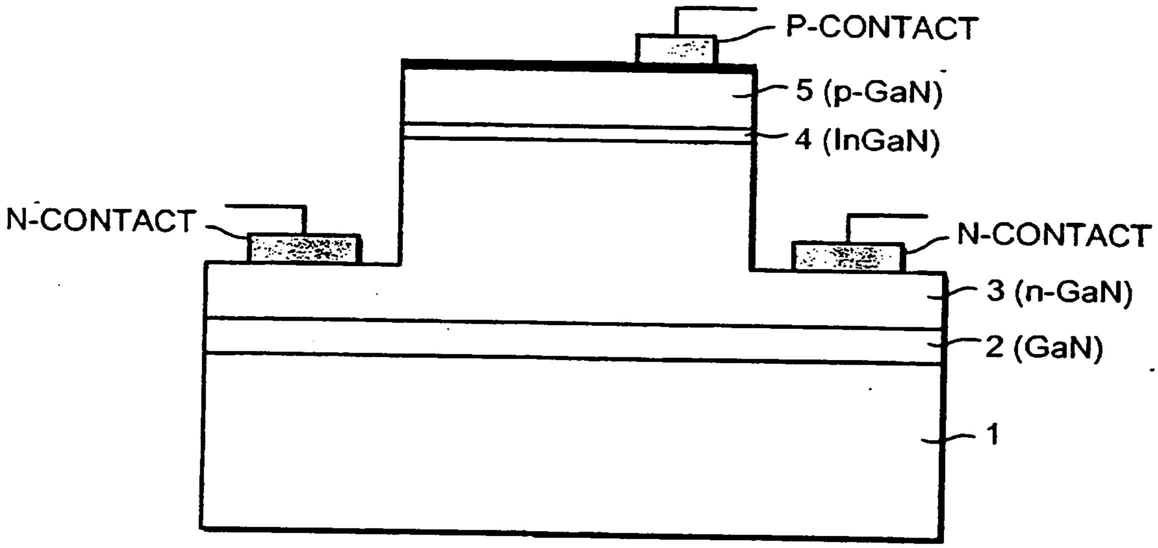
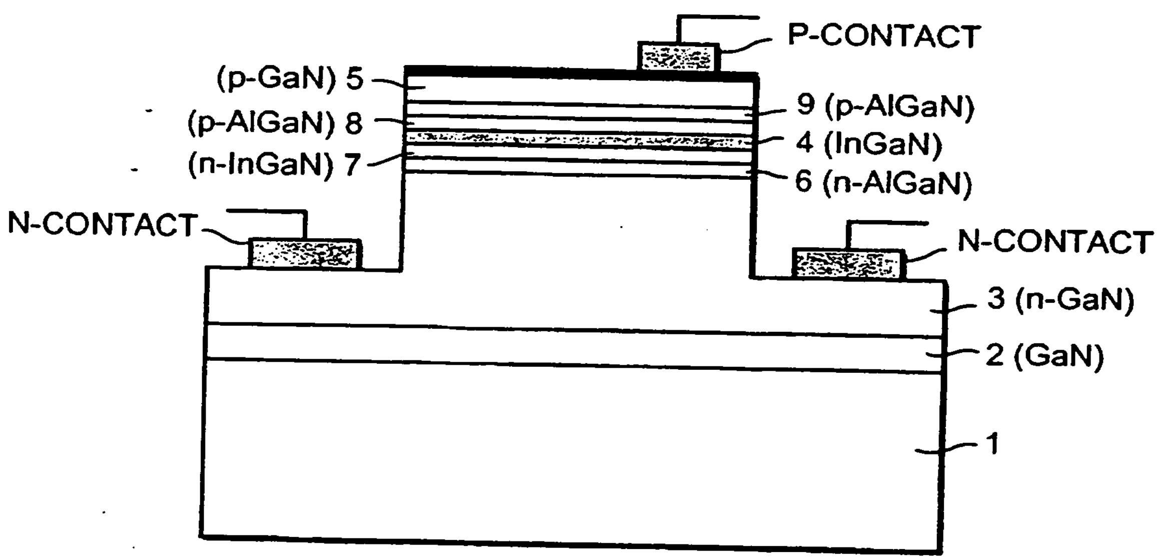


P-CONTACT
5 (p-GaN)
4 (InGaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (GaN)
1

FIG. 1



P-CONTACT
(p-GaN) 5
(p-AlGaN) 8
(n-InGaN) 7
9 (p-AlGaN)
4 (InGaN)
6 (n-AlGaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (GaN)
1

FIG. 2

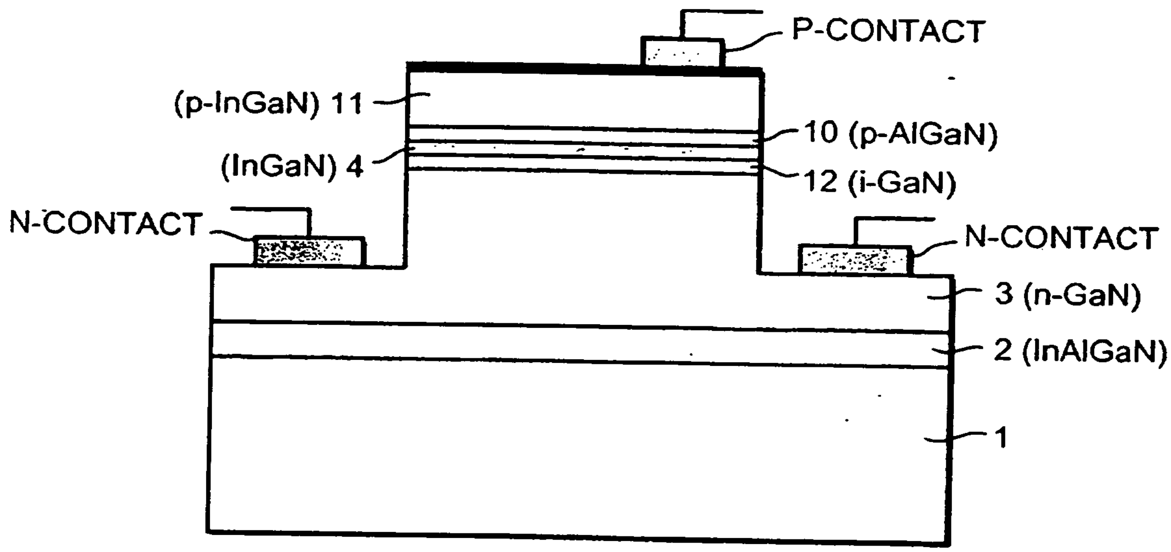

P-CONTACT
(p-InGaN) 11
10 (p-AlGaN)
(InGaN) 4
12 (i-GaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (InAlGaN)
1

FIG. 3

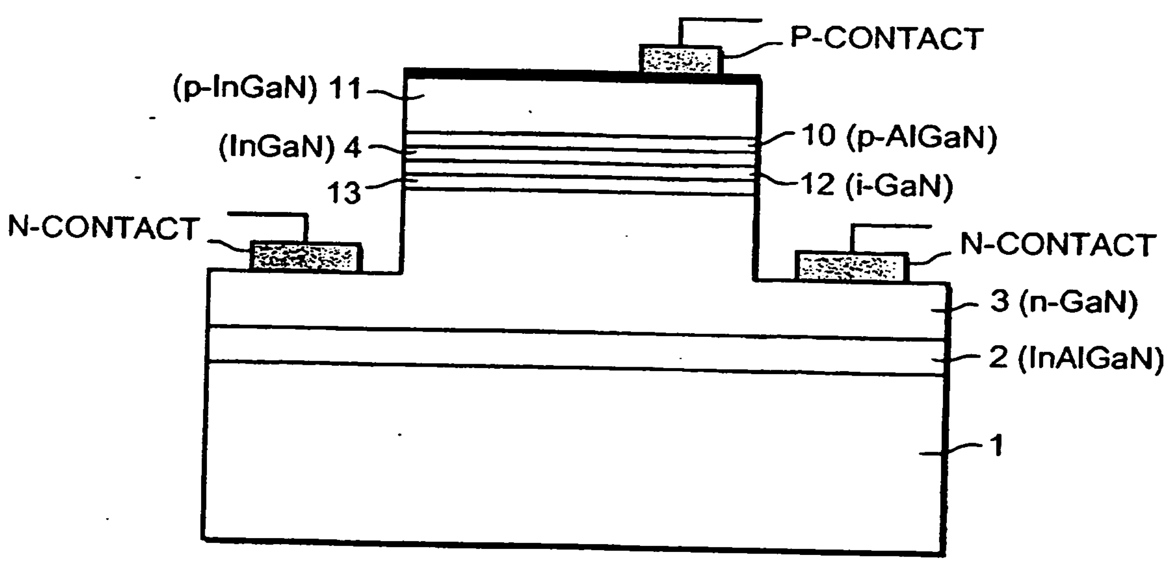

P-CONTACT
(p-InGaN) 11
10 (p-AlGaN)
(InGaN) 4
13
12 (i-GaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (InAlGaN)
1

FIG. 4

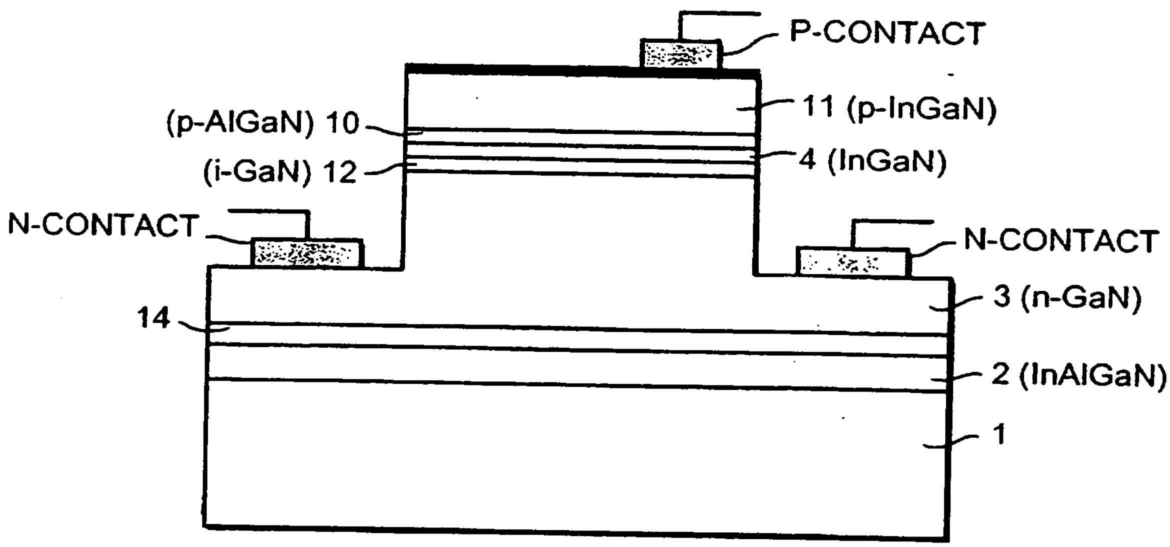

P-CONTACT
(p-AlGaN) 10
11 (p-InGaN)
(i-GaN) 12
4 (InGaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
14
2 (InAlGaN)
1

FIG. 5

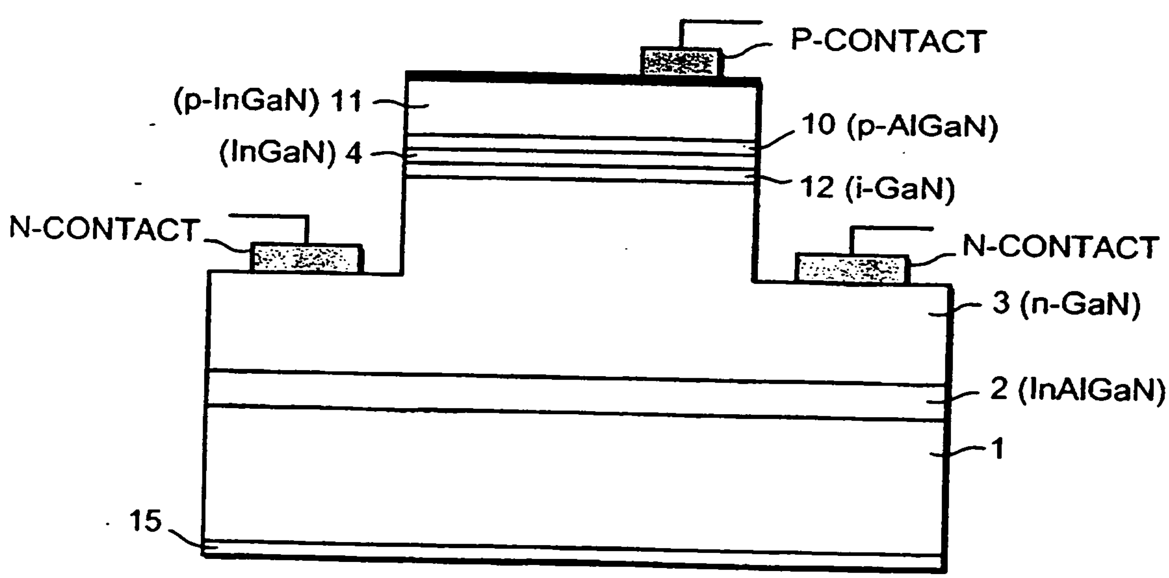

P-CONTACT
(p-InGaN) 11
10 (p-AlGaN)
(InGaN) 4
12 (i-GaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (InAlGaN)
1
15

FIG. 6

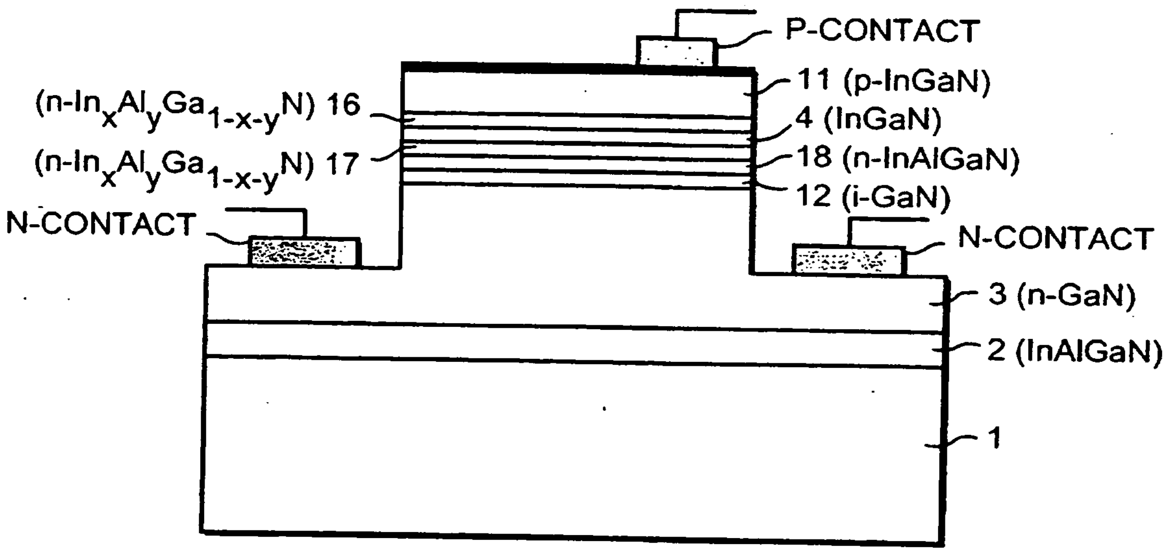

P-CONTACT
11 (p-InGaN)
(n-In$_x$Al$_y$Ga$_{1-x-y}$N) 16
4 (InGaN)
(n-In$_x$Al$_y$Ga$_{1-x-y}$N) 17
18 (n-InAlGaN)
12 (i-GaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (InAlGaN)
1

FIG. 7

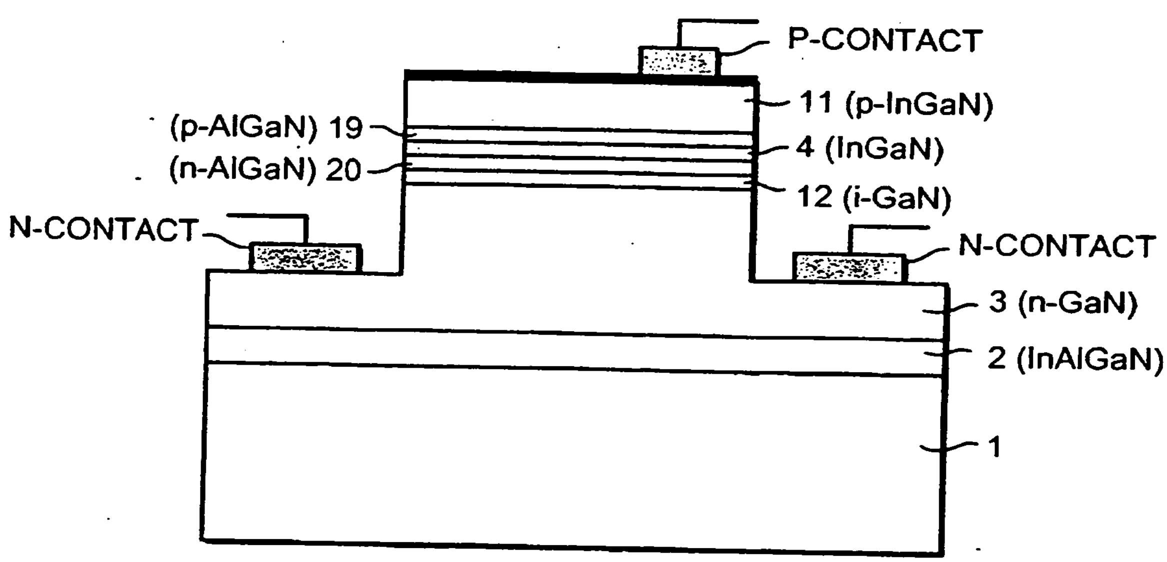

P-CONTACT
11 (p-InGaN)
(p-AlGaN) 19
4 (InGaN)
(n-AlGaN) 20
12 (i-GaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (InAlGaN)
1

FIG. 8

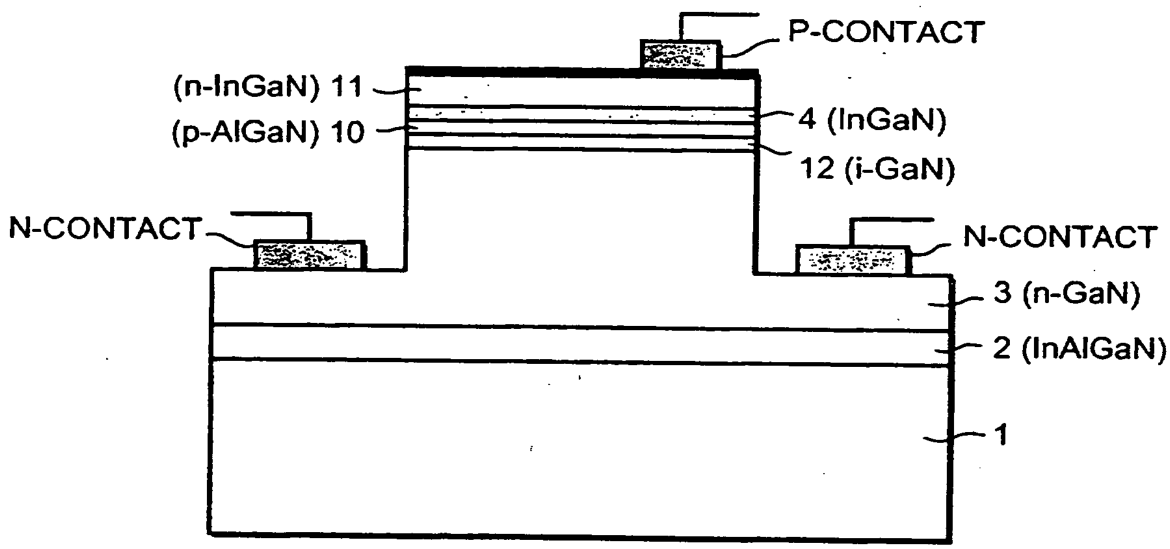

P-CONTACT
(n-InGaN) 11
(p-AlGaN) 10
4 (InGaN)
12 (i-GaN)
N-CONTACT
N-CONTACT
3 (n-GaN)
2 (InAlGaN)
1

FIG. 9

SEMICONDUCTOR DEVICES

The present invention relates to semiconductor devices, more particularly light-emitting diodes (LEDs) and laser diodes (LDs).

According to the present invention, there is provided a light emitting diode structure with asymmetric claddings comprising:

a sapphire substrate with a thin porous surface layer or patterned porous structure to control the nucleation process of a quaternary InAIGaN buffer layer and reduce strains;

a quaternary InAIGaN buffer layer;

a n-GaN layer;

a tunnelling barrier and electron spreading layer made of III-V materials between said electron emitting layer and said active layer;

an active layer made of III-V materials and which creates single or multiple potential wells for electrons and holes where radiative recombination of electrons and holes occurs;

a hole emitting layer made of p-type AlGaN;

a p-type contact layer made of p-type InGaN; and

a metallic ohmic contact to the hole emitting layer.

Preferably, the tunnelling barrier and electron spreading layer has a thickness of 5 to 50 Å; the active layer has a width from 5 Å to 0.1 μm; the hole emitting layer has a width from 50 Å to 1 μm; and the p-type contact layer has a width from 50 Å to 1 μm. There may be an electron emitting layer (for example with a width from 50 Å to 1 μm) made of n-type or undoped III-V materials and which creates a potential well and electron accumulating layer for electrons.

In the design of an LED, there are the following to be achieved:

Good injection of holes in the active region.
Crystal-structure quality of the active region.
High internal efficiency.
Better light extraction.

To achieve the above, the following features are used in examples of the invention and are also features of the present invention, separately or in any combination.

Applying asymmetric claddings to prevent electron leakage from the active region.
Quaternary buffer layer.
Strained superlattices to stop threading dislocation penetration into the active region and to improve light extraction from the structure.
Quaternary alloy claddings to provide lattice-matching between claddings and the active region.
Laterally confined active region to prevent non-radiative recombination of carriers.

Porous sapphire surface to control nucleation process of a quarternary alloy buffer layer and to reduce strains inside the epitaxial layers.

Fig. 1 shows a simple conventional structure of a GaN-based LED, comprising a sapphire substrate 1; a GaN buffer 2; a n-GaN layer 3; an InGaN active layer 4; a p-GaN layer 5; an n-contact; and a p-contact.

Fig. 2 shows a prior art GaN-based single quantum well LED with symmetric claddings, comprising: a sapphire substrate; a GaN buffer 2; a n-GaN layer 3; a lower n-AlGaN second cladding layer 6; a lower n-InGaN first cladding layer 7; an InGaN active layer 4; an upper p-AlGaN first cladding layer 8; an upper p-AlGaN second cladding layer 9; a p-GaN layer 5; an n-contact and a p-contact.

In this invention, asymmetric claddings to prevent electron leakage from the active region are employed to overcome problems related to poor p-type mobility.

In Fig. 3, an additional p-AlGaN cladding layer 10 is added and contact p-GaN layer 5 of Fig. 1 is replaced by p-IngaN layer 11. An additional i-GaN current spreading layer 12 is also added for better lateral uniformity of electron injection.

In Fig. 4 an additional electron emitting layer 13 is added for better lateral uniformity of electron injection.

In Fig. 5 an additional threading-dislocation-stopping layer 14 based on a strained superlattice provided either by an alternated superlattice structure or by a

distributed Bragg reflector layer which also acts as a mirror.

In Fig. 6 an external mirror 15 based on a metal layer or a metal-dielectric interference filter is used.

In Fig. 7 the strains in the active layer 4 are suppressed with tuning of quaternary alloy compositions in claddings 16 and 17 to achieve lattice-match. An additional graded cladding layer 18 serves the same purposes.

Fig. 8 shows an advanced structure which employs a lateral confinement of carriers inside the active region 4 which consists of separated InGaN islands embedded in the wider-gap matrix provided by confinement layers 19 and 20.

Fig. 9 shows an inverted version of the structure of Fig. 3 which makes it easier to prepare a front transparent metal contact.

In the above examples, crystals of a GaN-based compound semiconductor (3) are grown on the surface of buffer layer 2 represented by formula $(Ga_xAl_{1-x})_yIn_{1-y}N$, where $0 \leq x \leq 1$, $0 \leq y \leq 1$ (Fig. 3). The incorporation of In suppresses the occurrence of crystal defects and thus has excellent crystallinity and considerably superior flatness. The incorporation of In also enhances the growth rate of the crystal and thus reduces the deposition time required for the buffer layer. It is difficult to grow a p-type GaN layer on conventional buffer layers because the film has extremely bad crystallinity. For this reason, conventionally, n-type GaN is grown on a sapphire substrate. According to an example of the present

invention, there is provided a growth method for p-type $(Ga_xAl_{1-x})_yIn_{1-y}N$ to be directly grown on the buffer with an inverted LED configuration (Fig. 9).

The following are also features of the invention, separately or in any combination:

The use of a sapphire substrate 1 with thin porous surface layer or patterned structure to control the nucleation process of a GaN based buffer layer and reduce strains. This porous surface layer or patterned structure can be produced by laser scanning, plasma etching or chemical vapour deposition growth with suitable masks.

The LED structures are asymmetrical. The main reason for this approach is that the mobility for p-type GaN (about few tens of $cm^2/V.sec$) is much lower than n-type GaN (300 $cm^2/V.sec$). This is very different from other types of compound semiconductor LED devices, which have compatible p- and n-type mobilities. Therefore extra layers introduced in the p-type GaN side prevent the leak of run away electrons (Figs. 3, 4, 5, 6 and 7).

The use of strained superlattices to stop threading dislocation penetration into the active region and improves light extraction from the structure (Fig. 5).

The use of quaternary alloy claddings to provide lattice-matching between claddings and the active region (Fig. 7).

The use of laterally confined active regions to prevent non-radiative recombination of carriers (Fig. 8). Such laterally confined active regions can be created using

quantum structures such as quantum dots with the composition $(Ga_xAl_{1-x})In_{1-y}N$.

CLAIMS

1. A light emitting diode structure with asymmetric claddings comprising:

a sapphire substrate with a thin porous surface layer or patterned porous structure to control the nucleation process of a quaternary InAIGaN buffer layer and reduce strains;

a quaternary InAIGaN buffer layer;

a n-GaN layer;

a tunnelling barrier and electron spreading layer made of III-V materials between said electron emitting layer and said active layer;

an active layer made of III-V materials and which creates single or multiple potential wells for electrons and holes where radiative recombination of electrons and holes occurs;

a hole emitting layer made of p-type AlGaN;

a p-type contact layer made of p-type InGaN; and

a metallic ohmic contact to the hole emitting layer.

2. A structure according to claim 1, wherein the active layer has a thickness of 5 to 50 Å; the active layer has a width from 5Å to 0.1 μm; the hole emitting

layer has a width from 50 Å to 1 μm; and the p-type contact layer has a width from 50 Å to 1 μm.

3. A structure according to claim 1, wherein, an electron emitting layer made of n-type or undoped III-V materials is added and which creates a potential well and electron accumulating layer for electrons.

4. A structure according to claim 1, wherein the porous surface layer or patterned structure is produced by laser scanning, plasma etching or chemical vapour deposition growth with suitable masks.

5. A structure according to claim 1 which is an asymmetrical structure.

6. A structure according to claim 1, using a strained superlattice to stop threading dislocation penetration into the active region and improve light extraction from the structure.

7. A structure according to claim 1, using a quaternary alloy cladding to provide lattice-matching between claddings and an active region.

8. A structure according to claim 1, using laterally confined active regions to prevent non-radiative recombination of carriers.

Application No:	GB 9928531.4	**Examiner:**	COLIN STONE
Claims searched:	All	**Date of search:**	14 March 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H1K(KEAA,KEAX,KELD,KELX)

Int Cl (Ed.7): H01L

Other: ON LINE,W.P.I.,EPODOC,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A,E	GB 2338107 A	HEWLETT-PACKARD	
A	GB 2317053 A	HEWLETT-PACKARD	
A	US 5798537	TOSHIBA	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.